Effects of Large-Scale PV and Wind Energy Integration on Electricity Supply and Demand Balance in Western Japan, Based on Zero Nuclear Scenarios

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- This is a joint research by

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■ Aim of research

➢Estimating impacts of high penetration of Photovoltaic(PV) and Wind power on Supply–Demand Balance of the Western Japan Grid

■Points for analysis

- Western Japan Grid, (Kyusyu and Shikoku Zones, mainly)
- **High scenario** (PV 2 times from 2016), Optimizing fuel cost
- Use of Pumped Storage System (PSS) by pumping-up PV power, **'PV Pump-UP'**
- Estimating necessary volume of **Demand Response** (DR)
- Maximum use of **Interzone tie-lines for transporting PV power**
- **Control Reserve* activation beyond the zone**

* Regelleistung

■Method:

- **Minimizing daily fuel cost** of Scheduled Supply and Control Reserve activation
- **Base** scenario (PV, wind power in 2016) , **High** scenario (PV 2 times, wind 2 times)
- Optimization calculation by Matlab ‘Optimization tool box ‘
- Data in this research:

  Kyusyu and Shikoku zone:

  Generation capacity, Demand, PV and wind output in 2016,

  Renewable energy capacity in 2016

  Kyushu Electric Power Company, Shikoku Electric Power Company,

  METI (Ministry of Economy, Trade and Industry), OCCTO.

Japan's Grid Structure

Generation Companies are
Transmission system operators
the Grids have **not** yet been unbundled.

Vertically Integrated Utilities

Hokkaido
Demand
max 5.2 GW
min 2.4 GW

50Hertz regions

AC/DC converter
DC Link 600MW

Tohoku
Demand
max 13.7 GW
min 6.3 GW

60Hertz regions

Kansai
Demand
max 26.6 GW
min 10.3 GW

Hokuriku
Demand
max 5.2 GW
min 2.0 GW

300MW

Chugoku
Demand
max 10.6 GW
min 4.8 GW

AC/DC
converter
DC Link

Tokyo
Demand max **53.3GW**
min 20.2MW

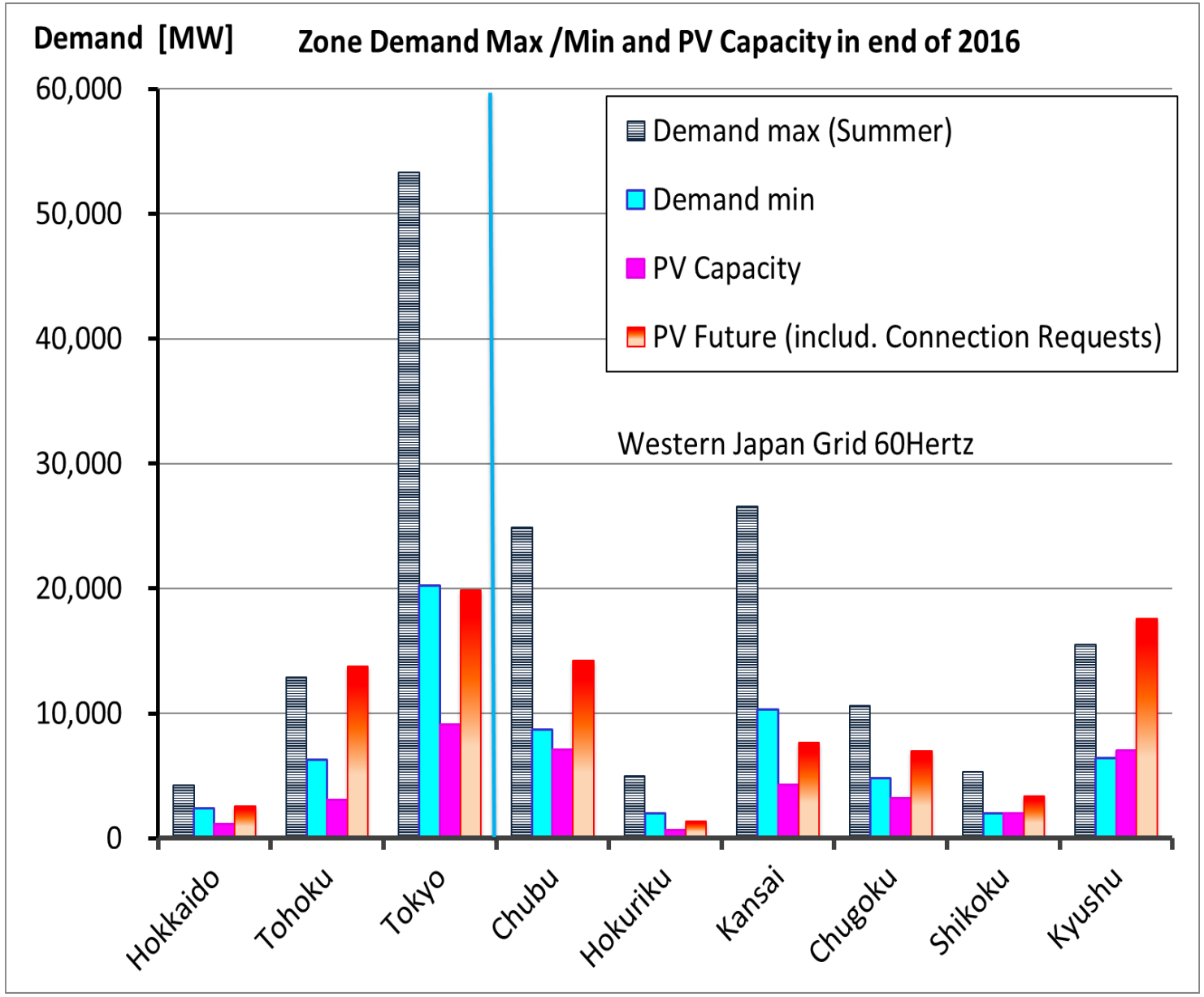
Kyushu
Demand
max 15.5 GW
min 6.4GW

Shikoku
Demand
max 5.3 GW
min 2.3 GW

Chubu
Demand
max 24.9 GW
min 8.7 GW

50Hz/60Hz convertor
1035MW

Backgrounds on Western Japan grids



- Kyusyu, Shikoku, and Chugoku zones have small demand & large PV capacity.
- Kyusyu has small demand (6 GW min, 15.5 GW max).
- Kyushu have huge quantity of Connection Requests from PV developers.
- If all connection requests are realized, Kyusyu would have 17.4 GW PV capacity.

Japan's grid operations: Differences from Germany 1

- 9 Transmission System Operators are 9 Generation Companies.
- Grid Operators (＝ Generation Companies) are **not obliged to expand Grid Capacity** to accommodate Renewable Generators.
- Generation Companies did impose **'Upper Limits of Connection'** (接続可能量) on PV and Wind systems.
- Grid operators are only **obliged to reduce Thermal Units Output with the Current Capacity,** for adapting RES feed-in

Japan’s grid operations: Differences from Germany 1

- Generation Companies **can keep the Current Capacity** of thermal units.
- No obligation to shutdown Thermal Units.
- Nuclear power has the first priority to be fed-into the grid. Nuclear has no obligation to reduce its output.
- **Generation Companies define** a level of **Technically Required Minimum Power** for grid reliability.

Japan's grid operations: Differences from Germany 2

- **Coal and Nuclear ('Long-term contracted, fixed units')** have the **first priority** to feed-in to Interzone tie-lines.
- A large capacity of Interzone tie-lines **have been reserved by** large-scale of **Coal and Nuclear** (since years ago). **'First come, First serve' rule**
- Interzone tie-lines shall be operated according to **'Scheduled Power Flow'**） from Coal and Nuclear ('計画潮流原則')
- >>> Interzone tie-lines are not used depending on PV power output.
- Supply-Demand is balanced in **Each zone**.
- Control Reserve is **not activated beyond the zone** in Japan.

  >>> there is no Netzregelverbund (Grid Control Cooperation) in Japan
- >>> **PV and Wind power is given a 'limited' priority to access to tie-lines and zone grid**.

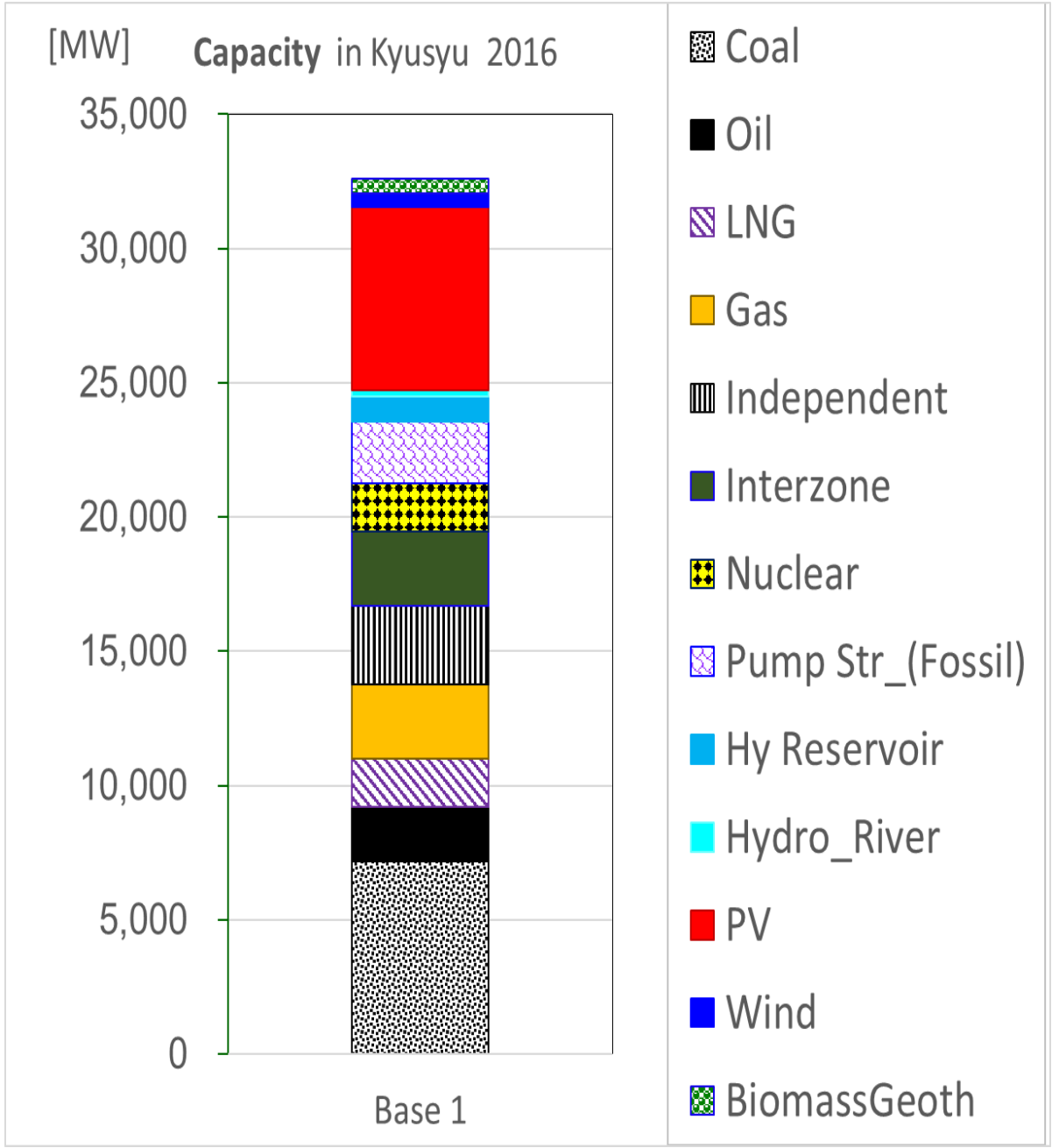
■**Kyusyu** Zone

■**Base Scenario**

- Generation Capacity in Aug 2016
- Nuclear capacity 4.7GW
- Nuclear 1.8 GW in operation
- Interzone tie-line 2.78GW
- Demand max 15.5 GW
- Demand min 6.4 GW
- Pumped Storage in Conventional Operation (Pump-Up in nighttime, and Generation in daytime/ evening) = **Fossil Pump-Up operation**

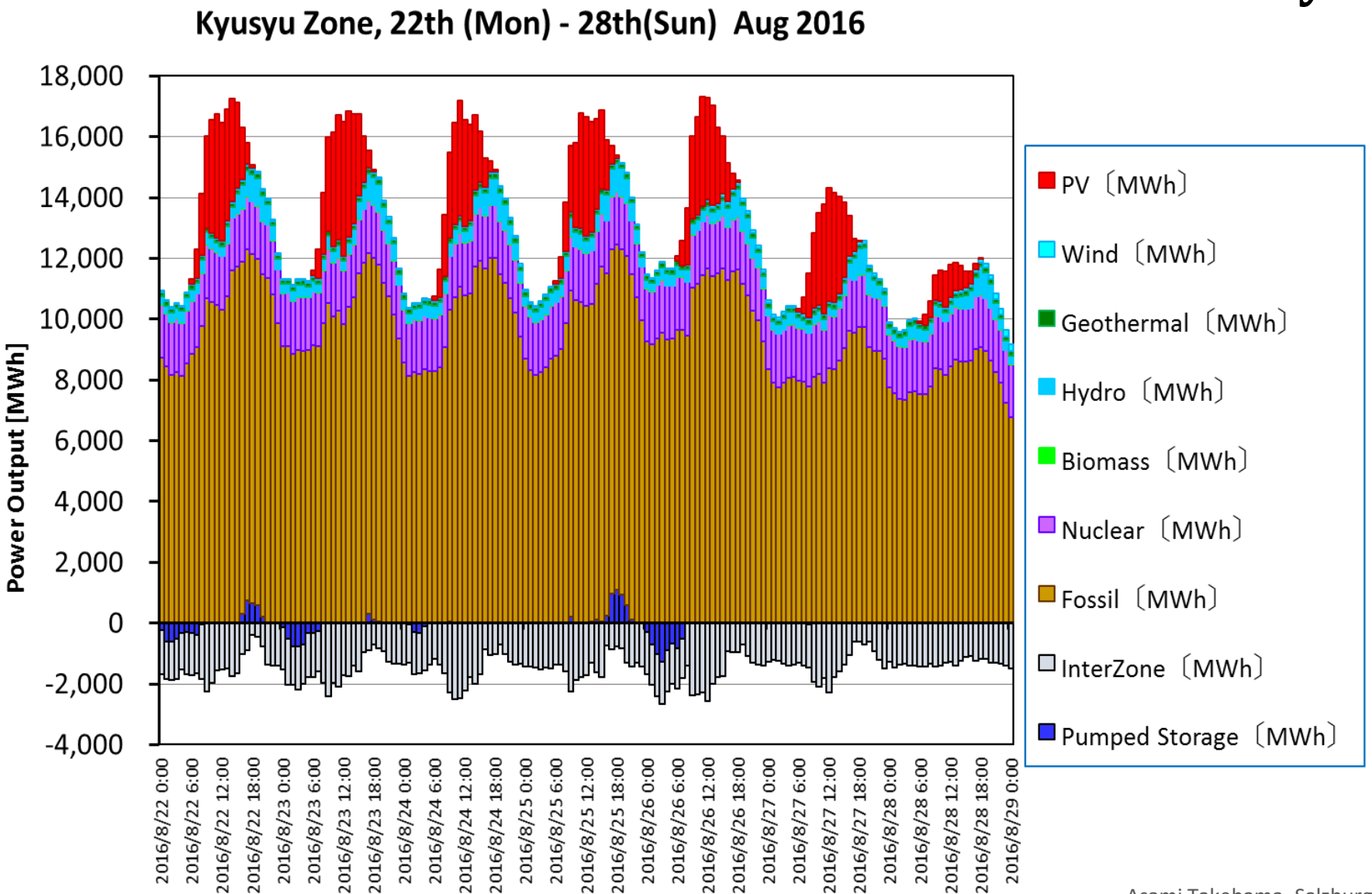
■**High Scenario**

- PV capacity **2 times** (13.8 GW)
- Zero Nuclear in operation
- **PV Pump-Up operation,** Pump-Up in daytime from PV output and Generating in evening
- **Interzone transmission from PV output**
- **Control Reserve is activated through Interzone tie-lines**
- Demand Response (DR) is activated up to 7 GW (*Dammy)



Kyusyu zone has high share of Coal capacity

Recent Operations of Pumped Storage system and PV output in **Kyusyu**, 2016 August



PV Pump-Up is not operated in summer 2016

Aug 2016, Peak Demand period,
Pump-Up in Night time/ morning
Generation in Evening

Spring, Autumn :
Pump-up in daytime,
Generation in evening
PV Pump-Up is partially operated

Source) Data obtained from Kyusyu Power Company, and OCCTO

Constraints of Unit Commitment and Pumped Storage Plants

- Upper/Lower limit of thermal power plant

$$P_{min} \leq P \leq Pmax$$

- Upper /Lower limit of Ramp Up/ Down rate

$$\text{Ramp}_{min} \leq \text{Ramp} \leq \text{Ramp}_{max}$$

- Capacity of Control Reserve at time (h)

  $\sum(Ccontrol) \geq 0.03^*$ Demand

  $\sum(Ccontrol) \geq \sum(0.05 * Cn)$

  Control Reserve (=Regelleistung)

- Available capacity of control reserve units must be larger than 3% of Demand at time t
- Coal and Nuclear plants are not used as Control Reserve units
- Available capacity of Control Reserve is at least 5% of each capacity of control reserve unit and Interzone at time t.
- Control reserve is supplies through Interzone（posi CR, Nega CR)

Assumptions for Unit Commitment

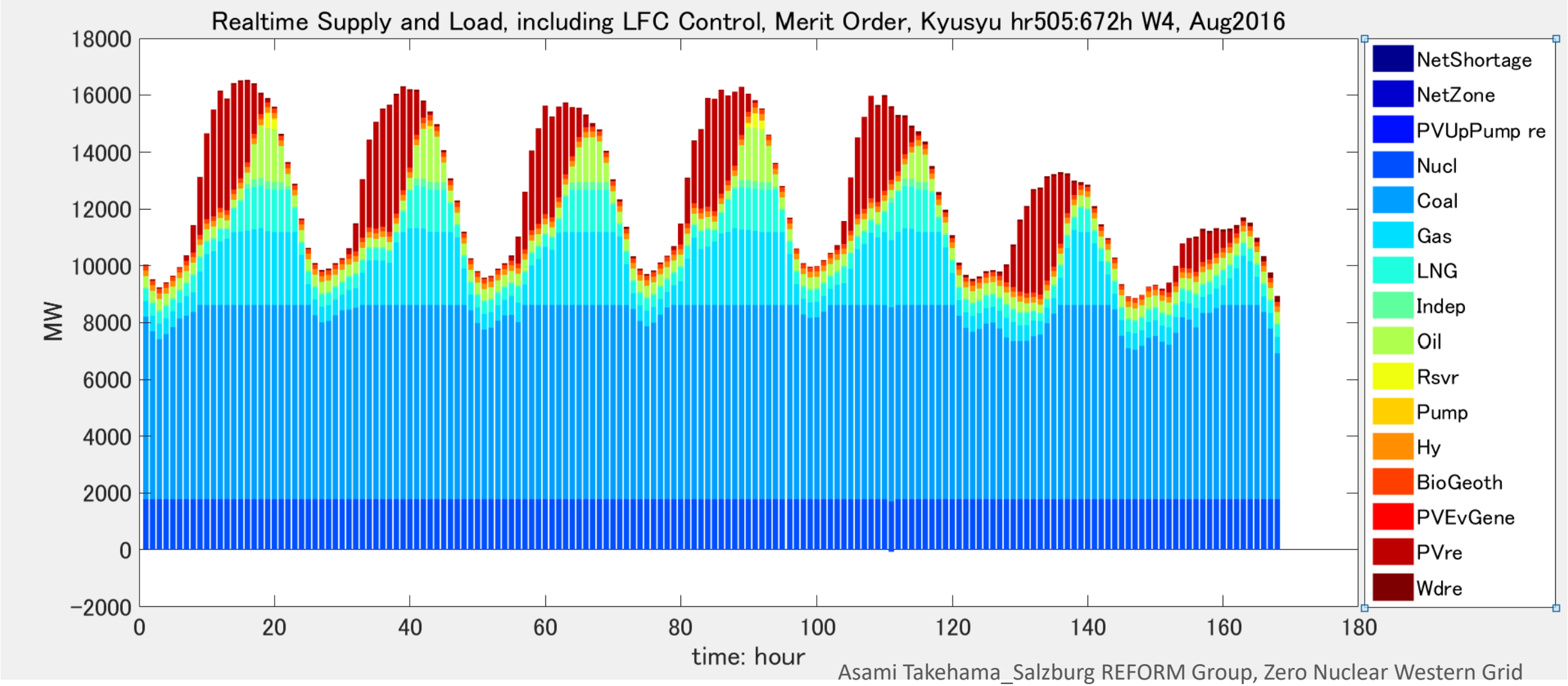
- Photovoltaic output forecast is calculated based on actual Solar Radiation in the past 1 hour (by Japan Meteorological Agency)
- No Curtailment on PV and Wind power
- PV and RES energy is fed-into the grid as a priority
- All feed-in from PV is distributed and transmitted to upper voltage grid, if necessary
- Grid congestion/ bottlenecks in distribution grids are not considered here.

Base 1 : Generation capacity 2016 Aug. in **Kyusyu**

Nuclear 1.8 GW in operation, Coal 7 GW, PV 6.9 GW

0% of PV power is Pumped-Up.

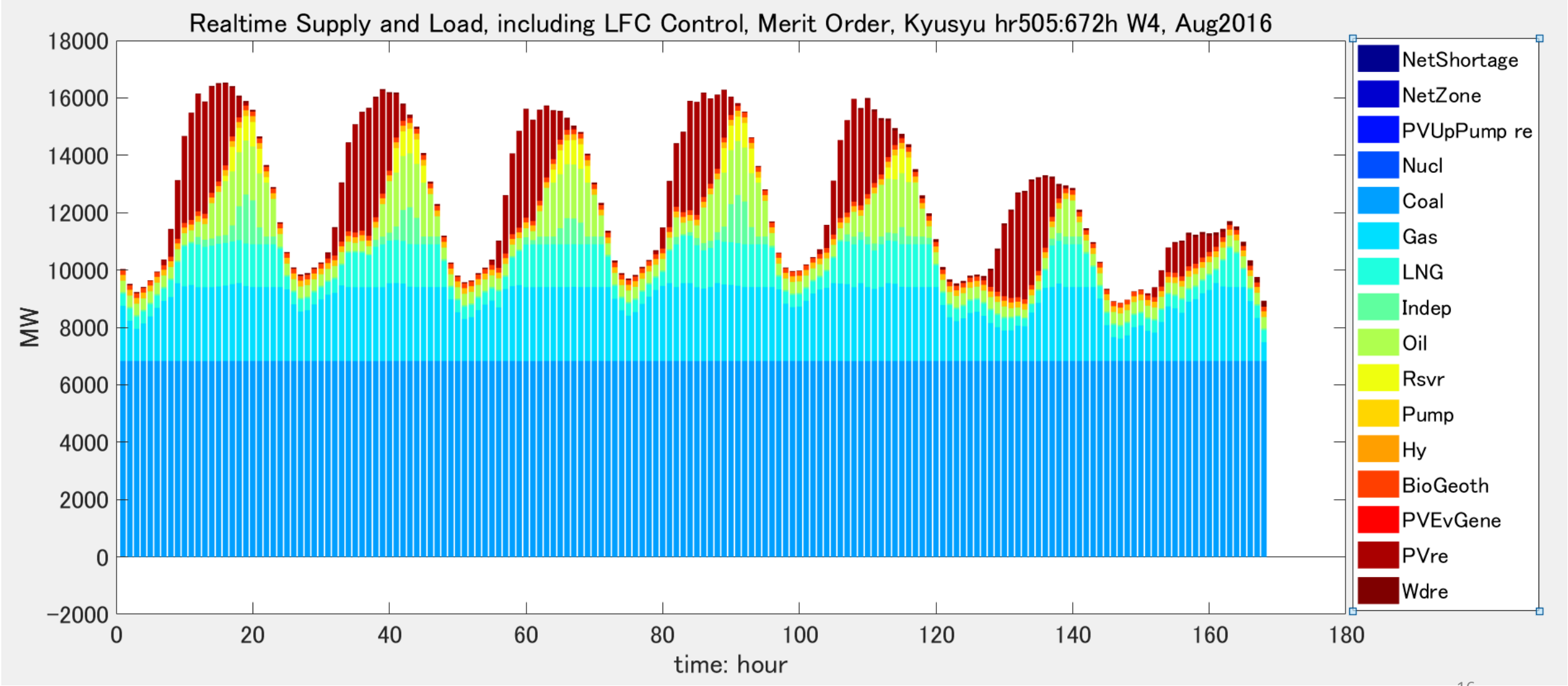
Coal plants have partial operation because of Nuclear plant in operation.



Base 2 : Zero Nuclear case , Kyusyu zone

Nuclear 0 GW >> Coal power is fully operated.

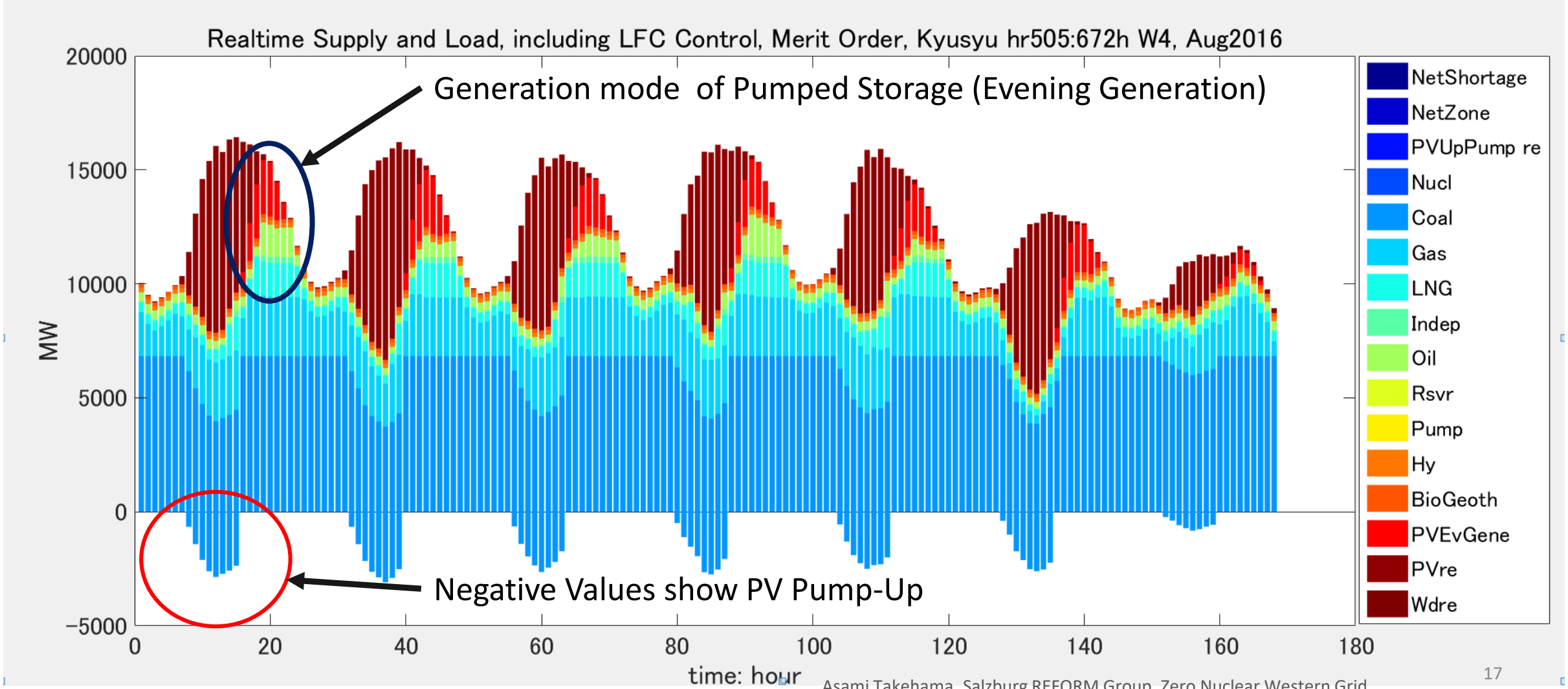
0% of PV power is Pumped-Up.



High Scenario, PV Capacity 2 times from 2016. **Kyusyu Zone**

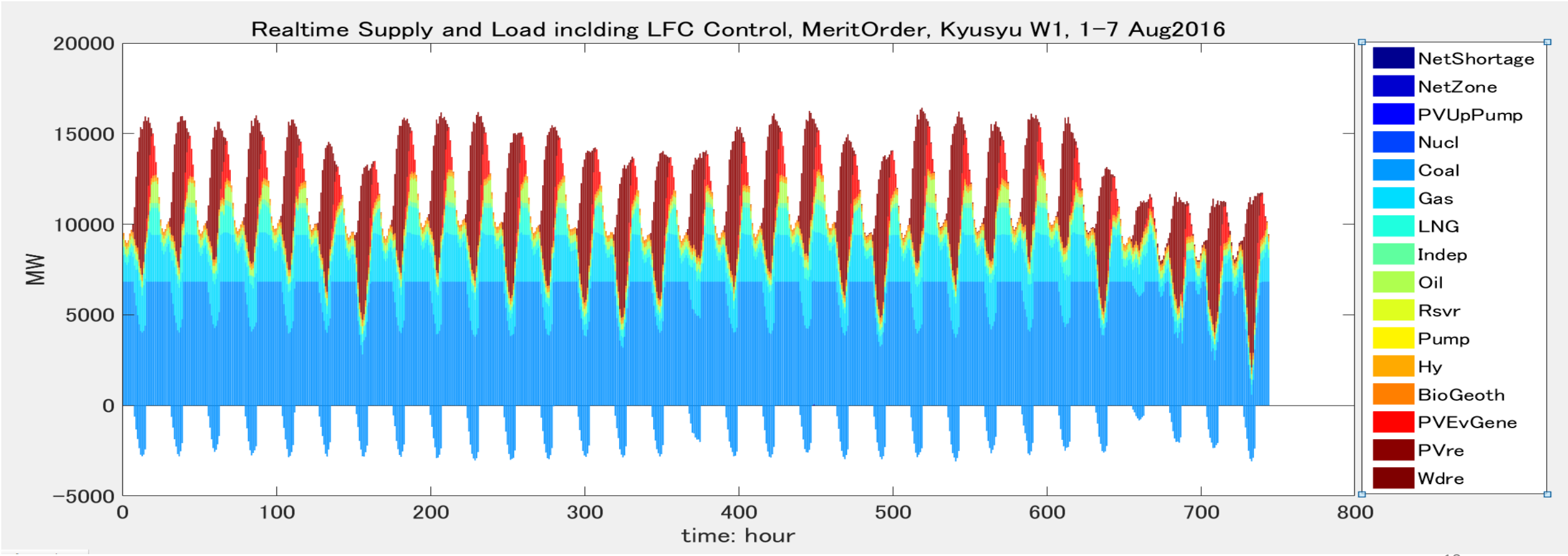
Nuclear 0 GW, Control Reserve is activated through interzone line.

Pumped-Storage: 35% PV Power is Pump-Up in daytime (PV Pump-Up). Generation mode in the evening.

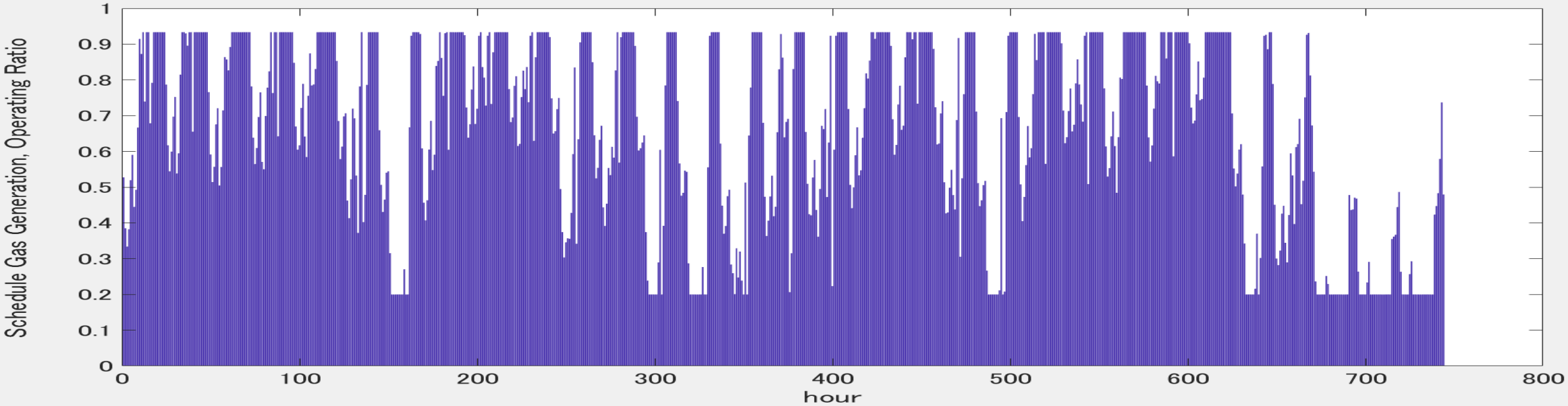


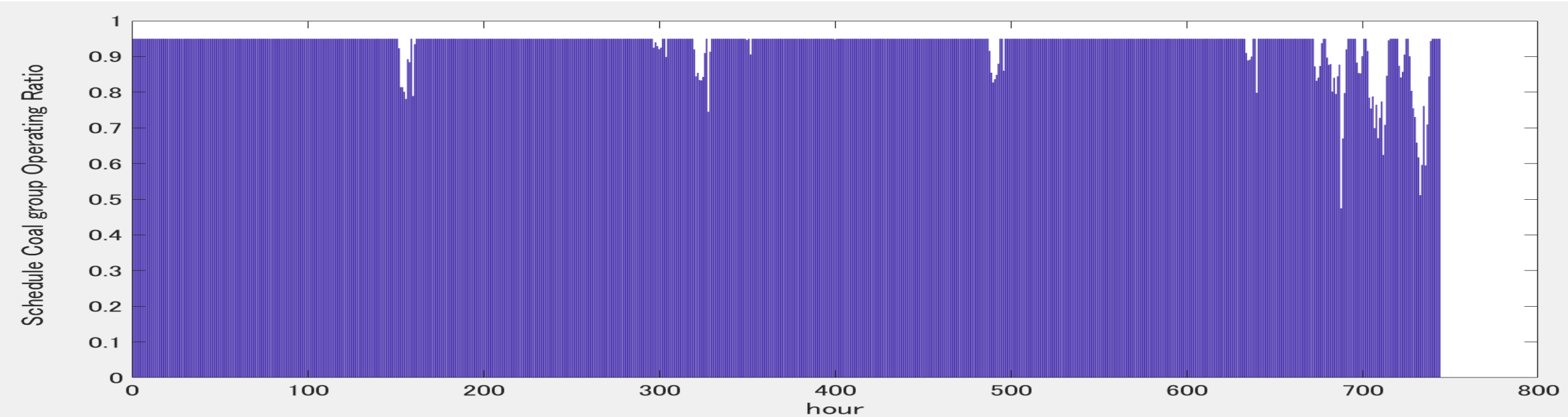
High Scenario, Kyusyu, August. PV Capacity 2 times 35% PV Power Pump-Up

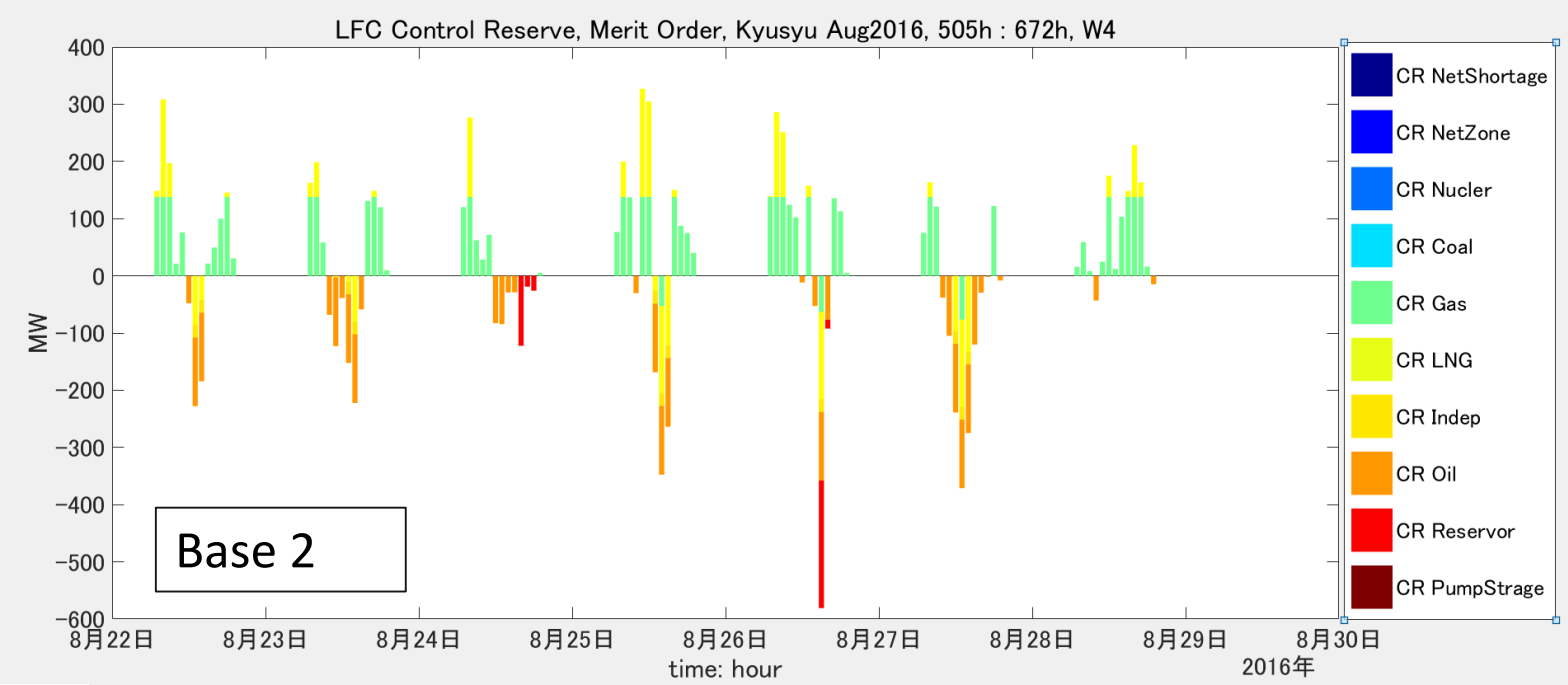
- on All 31 days in August , PV power could be pumped up, even on rainy days, due to high penetration of PV capacity.
- Large scale of Demand Response is needed, in order to accommodate large quantity of excess PV power.
- Required DR scale is around the scale of Upper Reservoir of Pumped Storage.

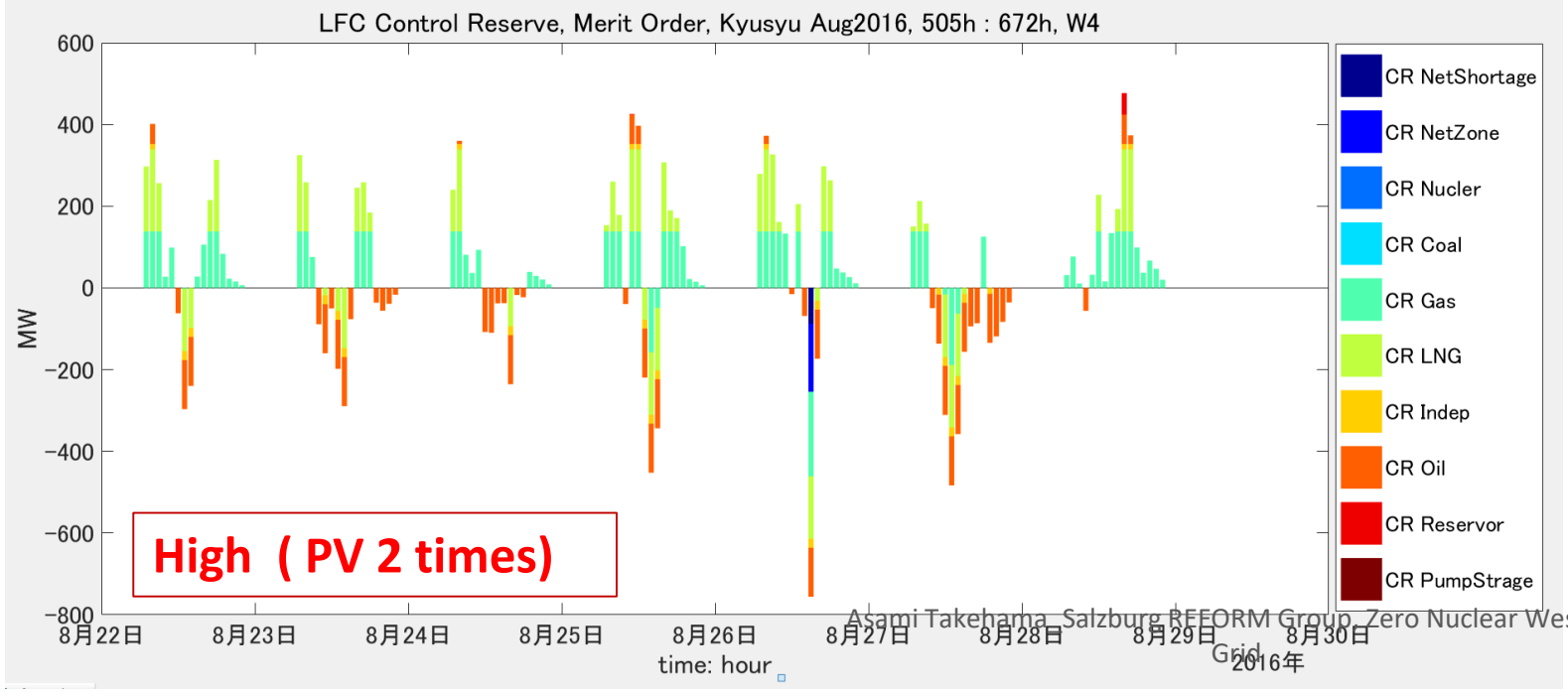


Coal plant and Gas CC plant operation ratios in High Scenario (Zero Nuclear, PV 2 times) Kyusyu





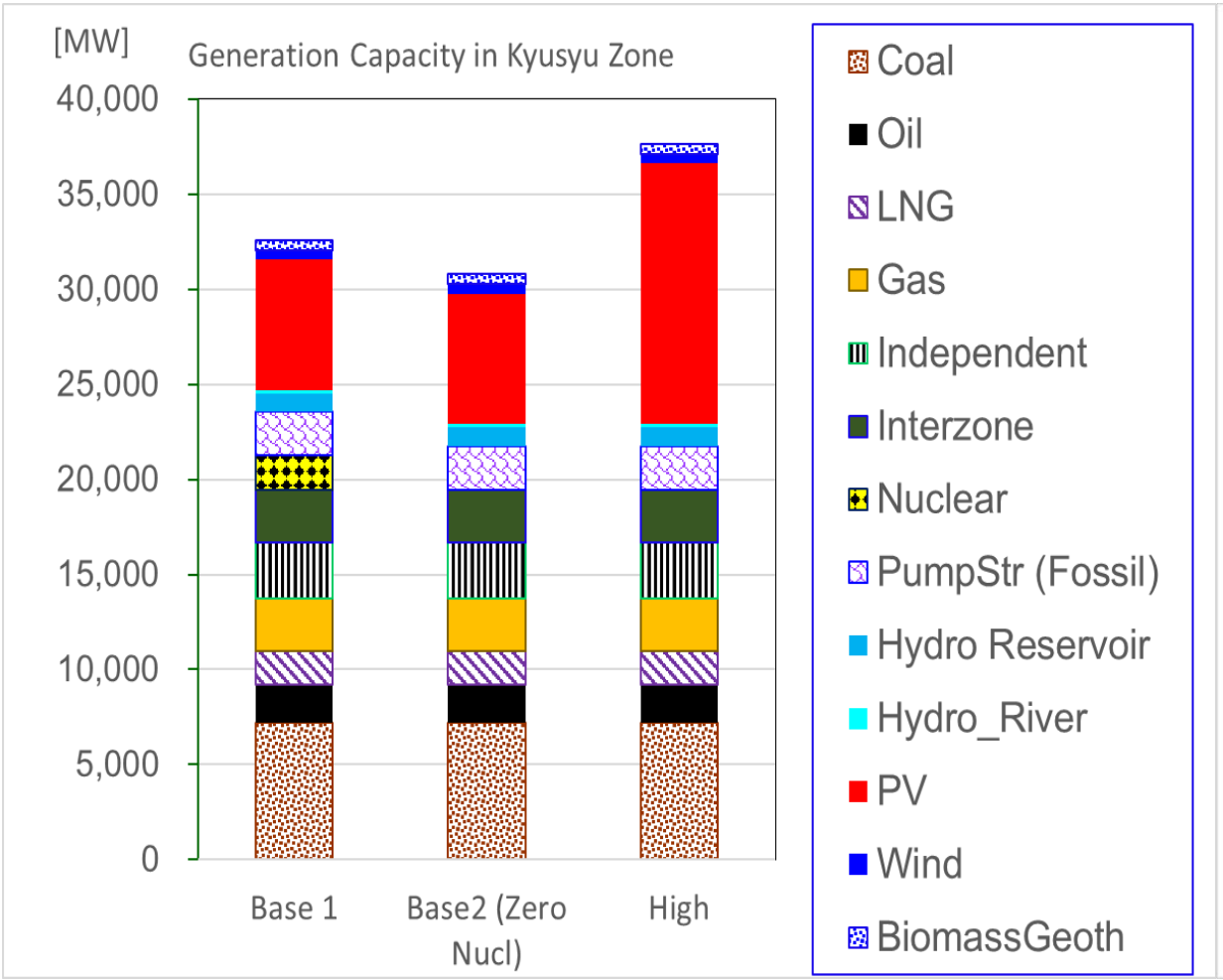


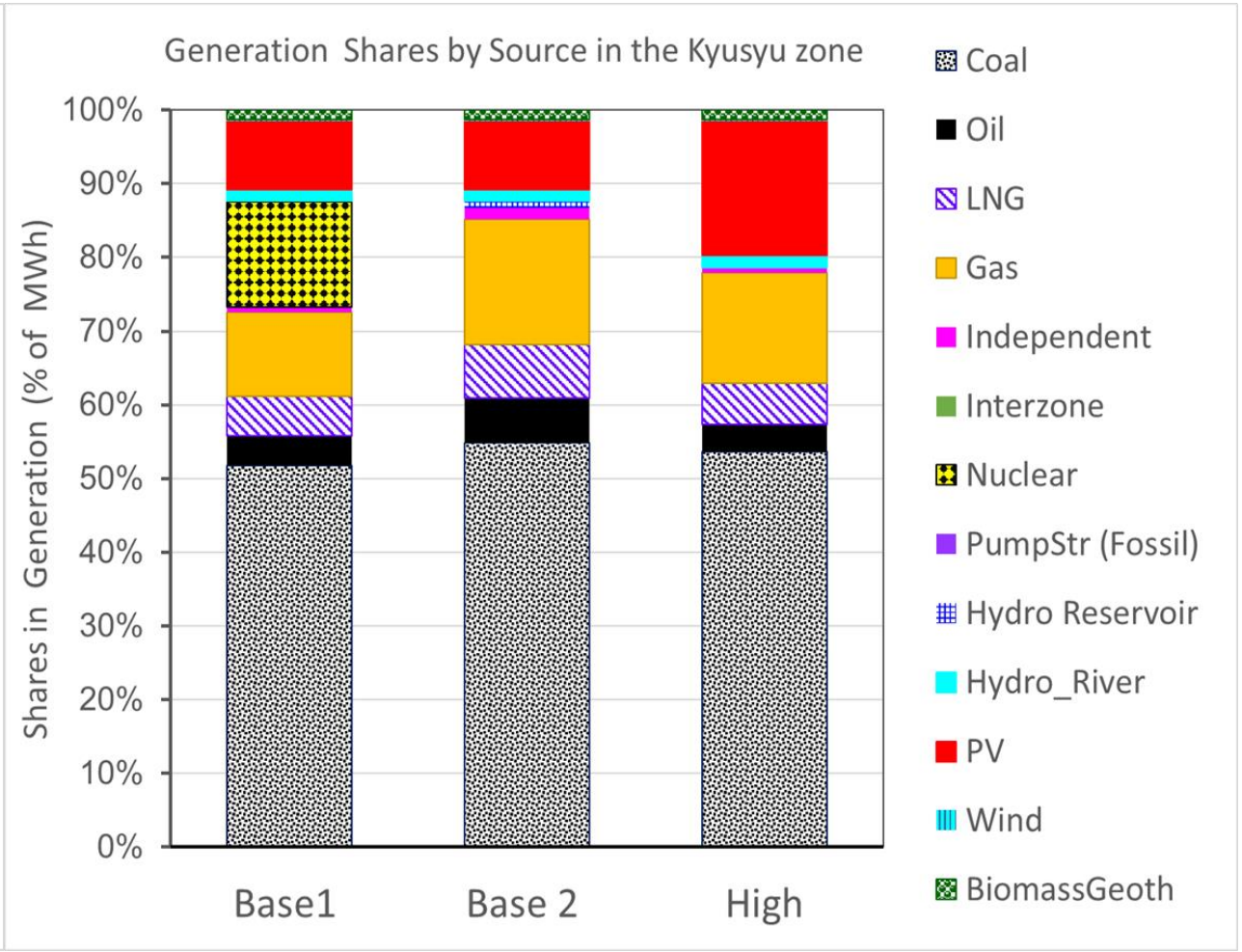


- High Scenario Kyusyu
- (PV 2 times, 35% PV Pumped Up)
- Due to large amount of PV feed in, availability of Negative Control Reserve becomes tight.
- Control reserve activation through Interzone Exchange becomes necessary.

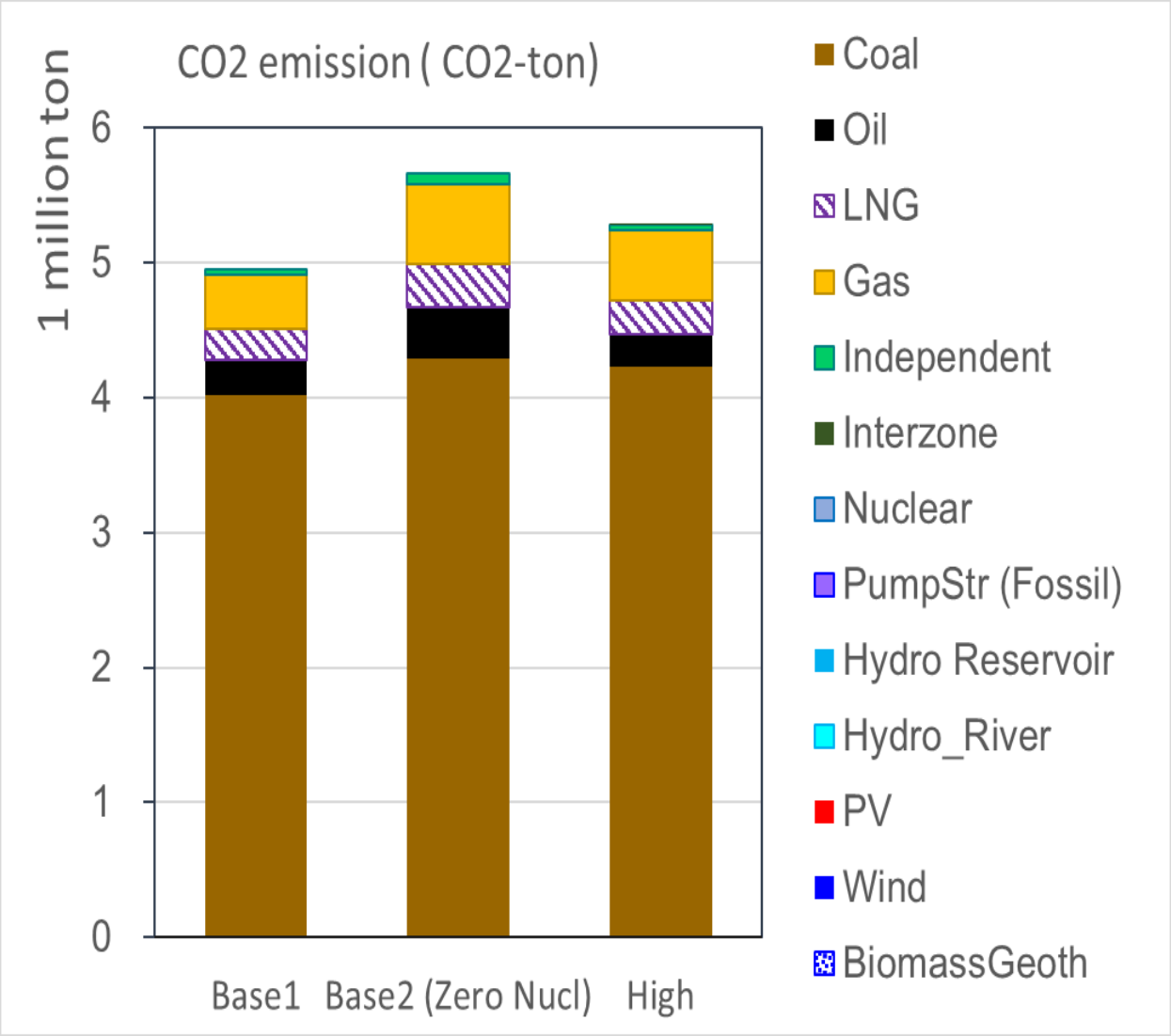
Results of Base 1, Base 2 (Zero Nuclear), High scenarios in **Kyusyu**.

In High scenario, Oil and LNG generation (MWh) has decreased.





CO2 emission has decreased by 7% in High Scenario. However, CO2 reduction from Coal has stagnated.



Kyusyu zone results

Renewable Share in Total Generation [% of MWh]		
Base1	Base2 (Zero Nucl)	**High**
12%	**13%**	**21%**
*Including Hydro and reservoir		

Average CO2 emission per kWh [CO2-kg/kWh]		
Base1	Base2 (Zero Nucl)	**High**
0.54	**0.61**	**0.57**

Average Fuel Cost [JPY/kWh]		
Base1	Base2 (Zero Nucl)	**High**
6.52	**8.15**	**6.68**

1 Euro = 130 JPY
0.76 ct = 1 JPY

■Conclusions in **Kyusyu** zone

- ➢High Scenario shows all 31 days in August have PV Pump-Up mode, even on rainy days.
- Even in peak demand period (Summer) , a risk of supply shortage is small.
- ➢High Scenario shows that : (compared to Base 2)
- Renewable energy share has increased from 13% to 21%
- CO2 emission has decreased from 0.61 to 0.57 [CO2kg/kWh]
- Average fuel cost has decreased from 8.15 to 6.68 [JPY/kWh]
- DR (Demand Response) is required to balance large-scale oversupplying electricity from PV.
- Reservoir capacity (20,000 MWh) is required for DR in summer peak demand period.
- PV Pump-Up operation must be recommended in summer peak demand period.

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Hokkaido
Demand
max 5.2 GW
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Demand
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50Hz/60Hz convertor
1035MW

Scenarios in Shikoku Zone

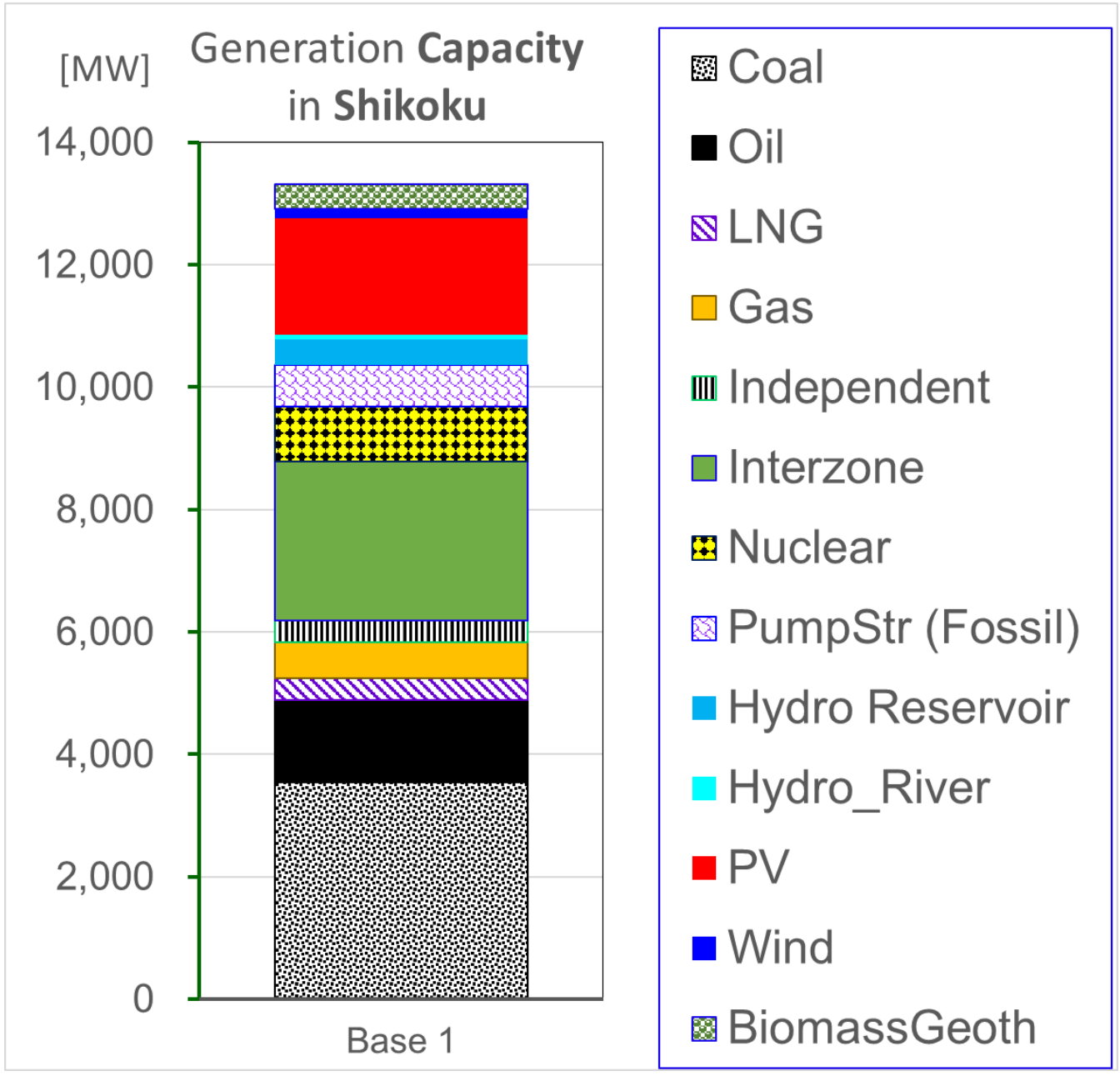
■Demand max 5.3 GW, min 2.3 GW

■Base

- PV Capacity 1.9 GW
- Wind Capacity 0.1 GW
- Nuclear 1.46 GW
- **Nuclear in Operation 0.9 GW**
- Inter Zone Tie-line capa. 2.6 GW
- Interzone Exchange of Fossil Power = 1.3 GW of coal power > Kansai
- Pumped Storage operation with **Fossil /Nuclear Pump-Up and** Evening Generation

■High

- PV 2 times from Base (3.8GW)
- Wind 2 times (0.2 GW)
- Nuclear 0 GW
- InterZone Tie-Line 2.6 GW from Renewables
- Pumped Storage in **PV Pump-Up**, **Evening Generation**
- Inerzone Export of Fossils = 0
- PV transport to Interzone 20% of PV Power

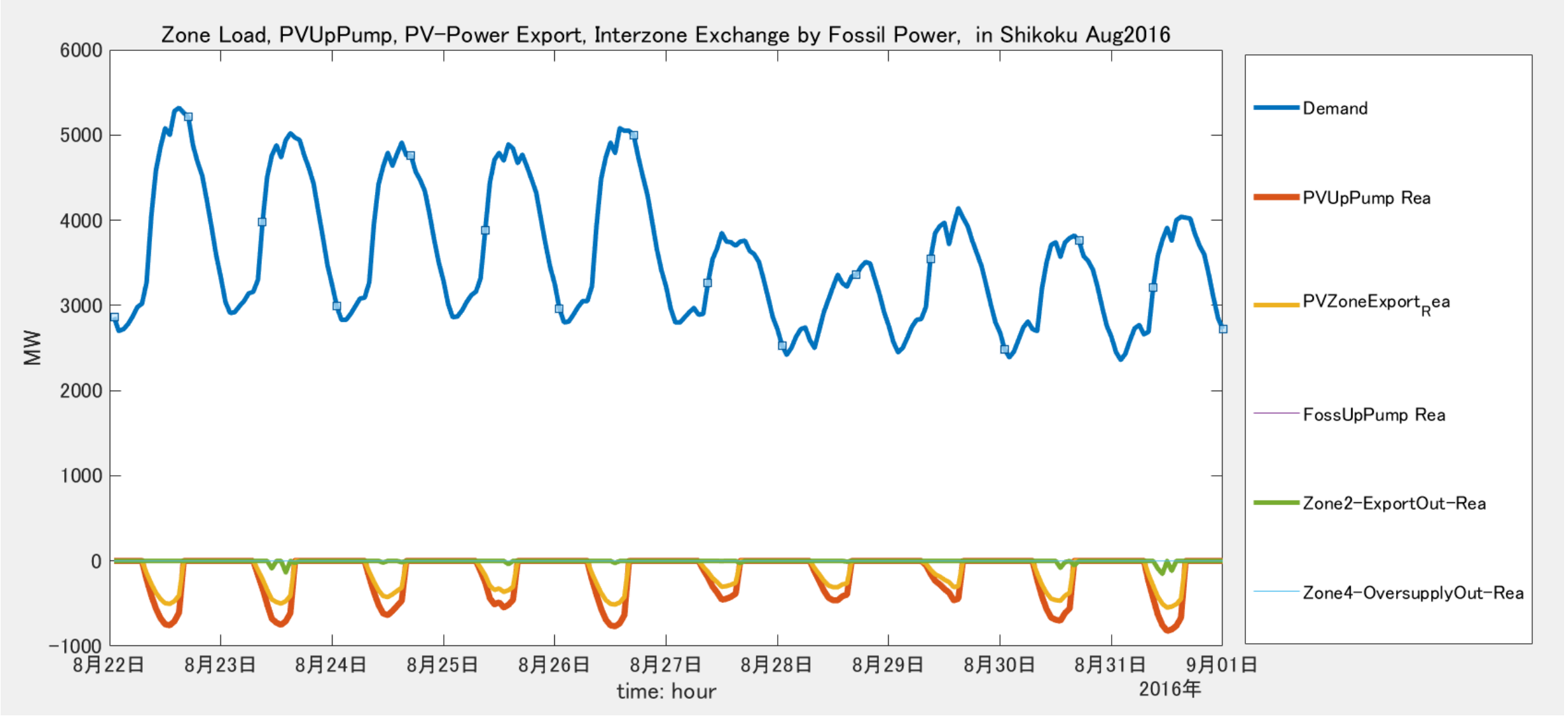


Shikoku Zone Capacity in 2016

Asami Takehama_Salzburg REFORM Group, Zero Nuclear Western Grid

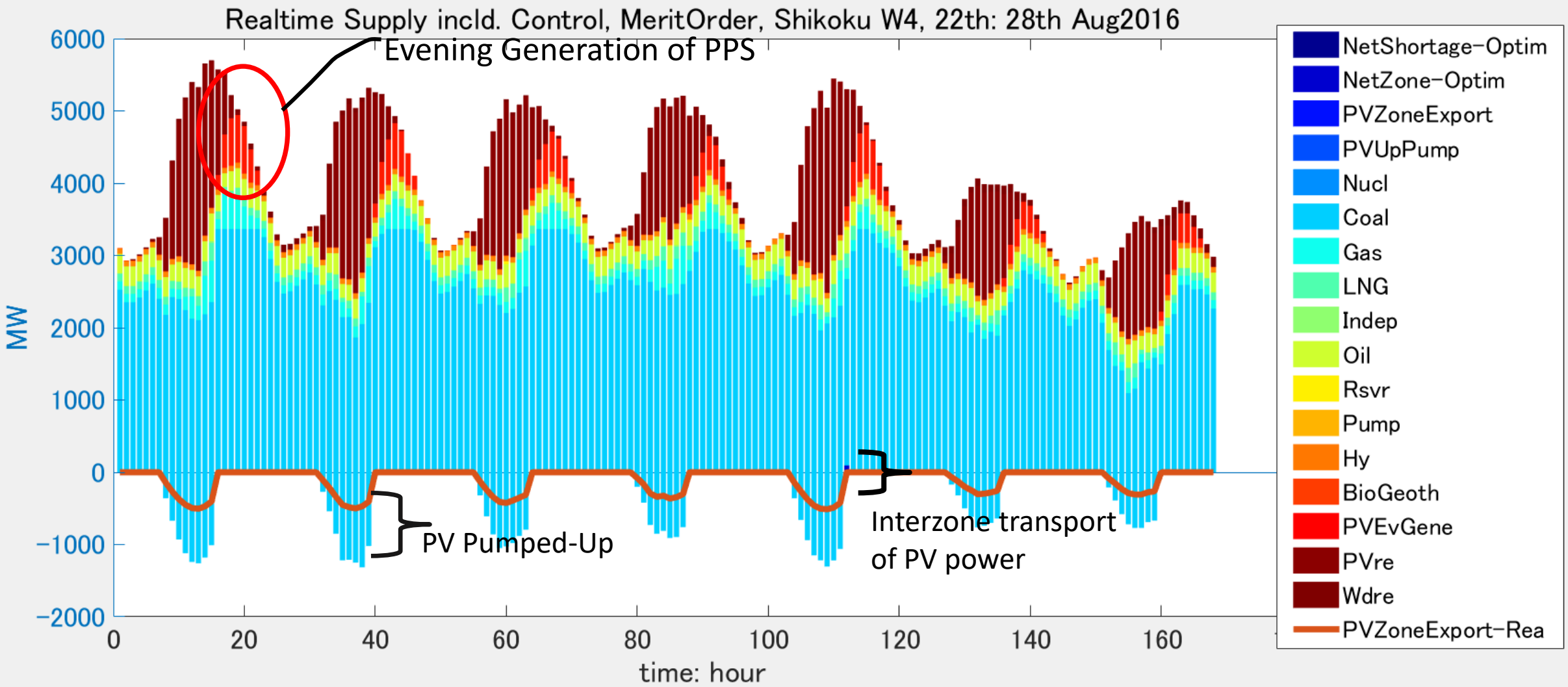
■ Shikoku zone, High Scenario

■ PV Power transport to Interzone line + PV Power Pump-Up



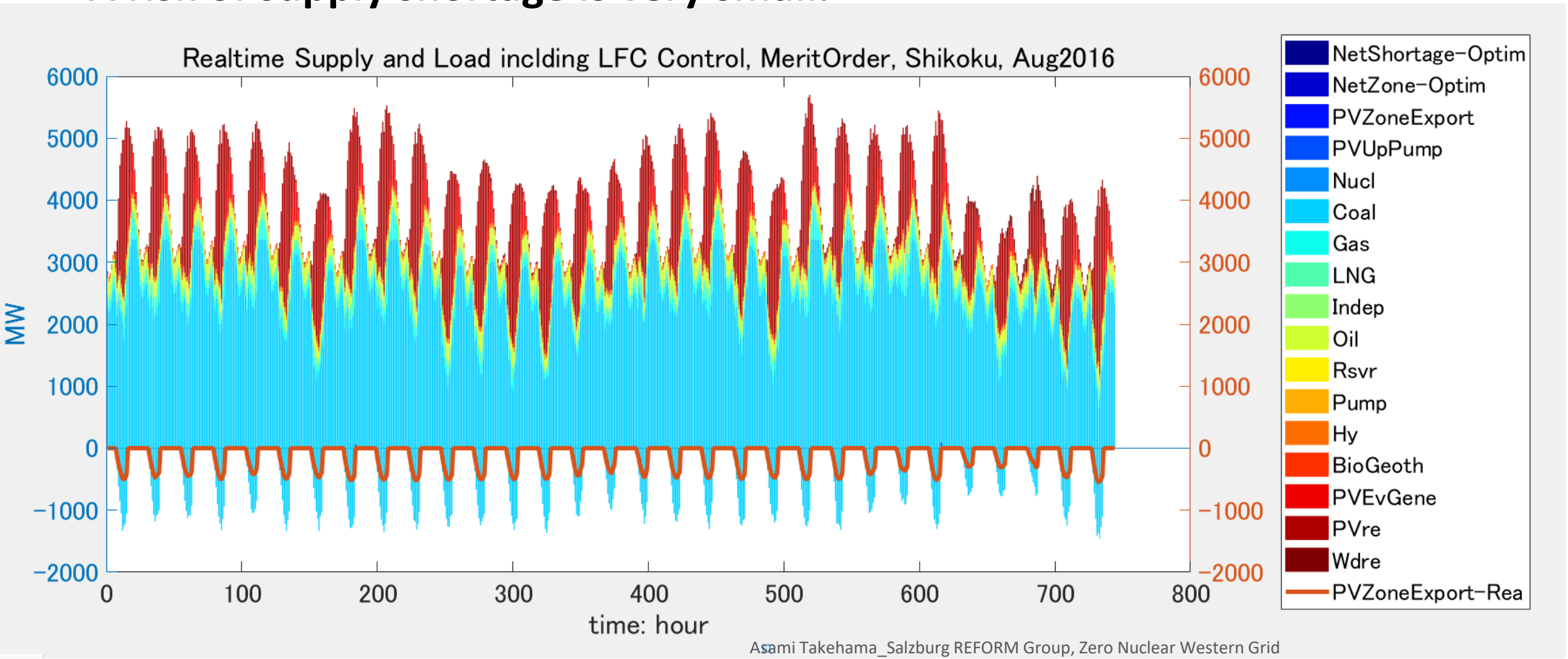
■ High Scenario in Shikoku Zone,

Pumped Storage with PV Pumped-Up and Evening Generation

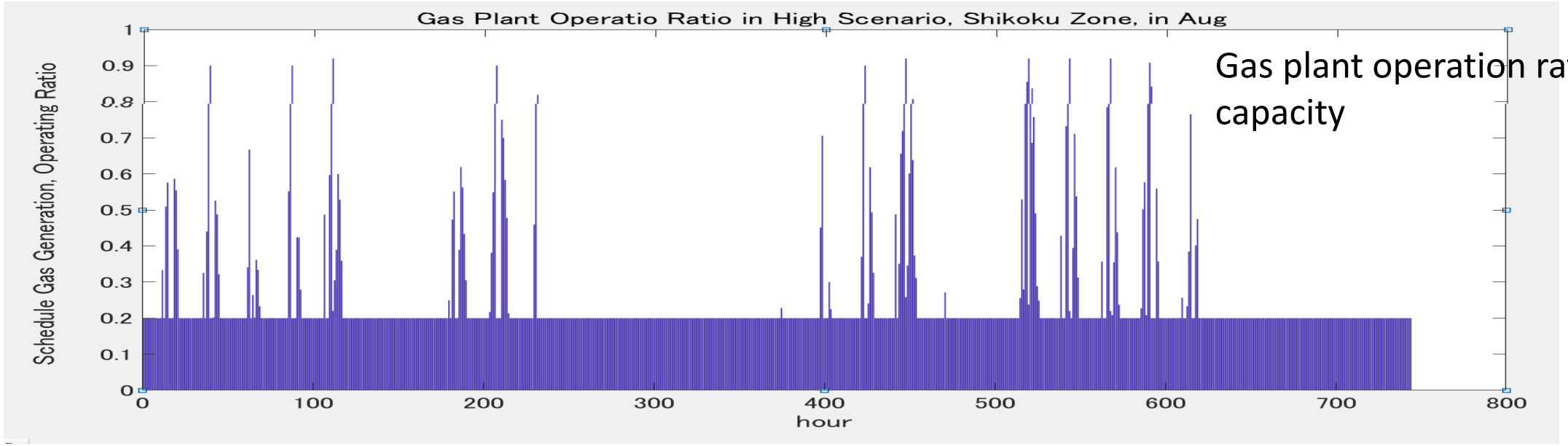


■ **High** Scenario in **Shikoku** zone

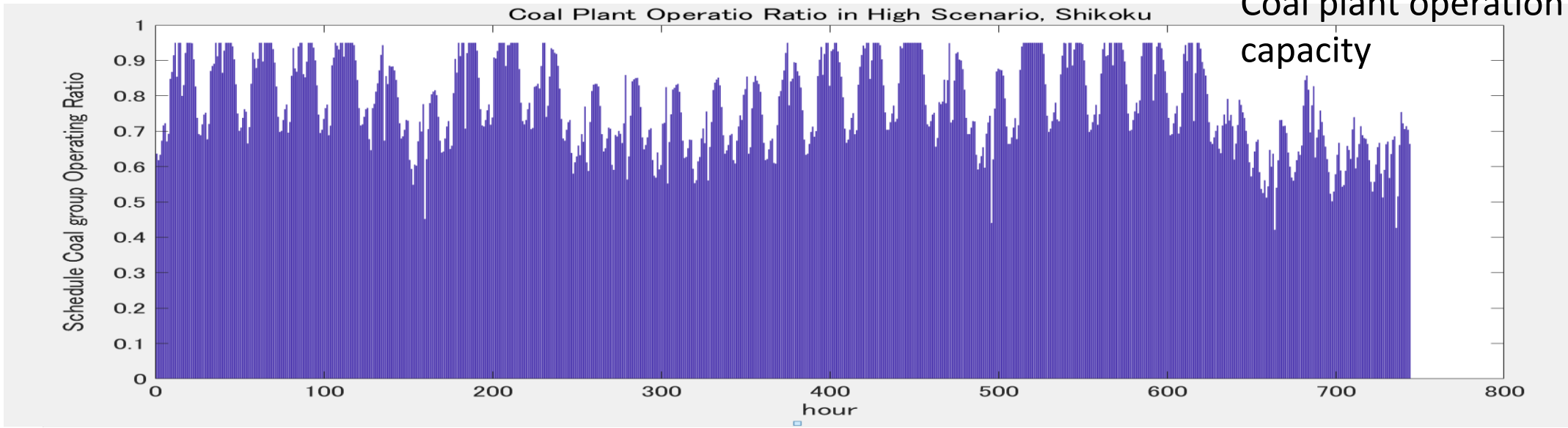
- on **All 31 days in August** including rainy days, **PV power could be pumped up** and generated in evening.
- **A risk of supply shortage is very small.**



■Operation Ratios of Gas plant and Coal plant.　High Scenario, **Shikoku** zone.



Gas plant operation ratio/ rated capacity

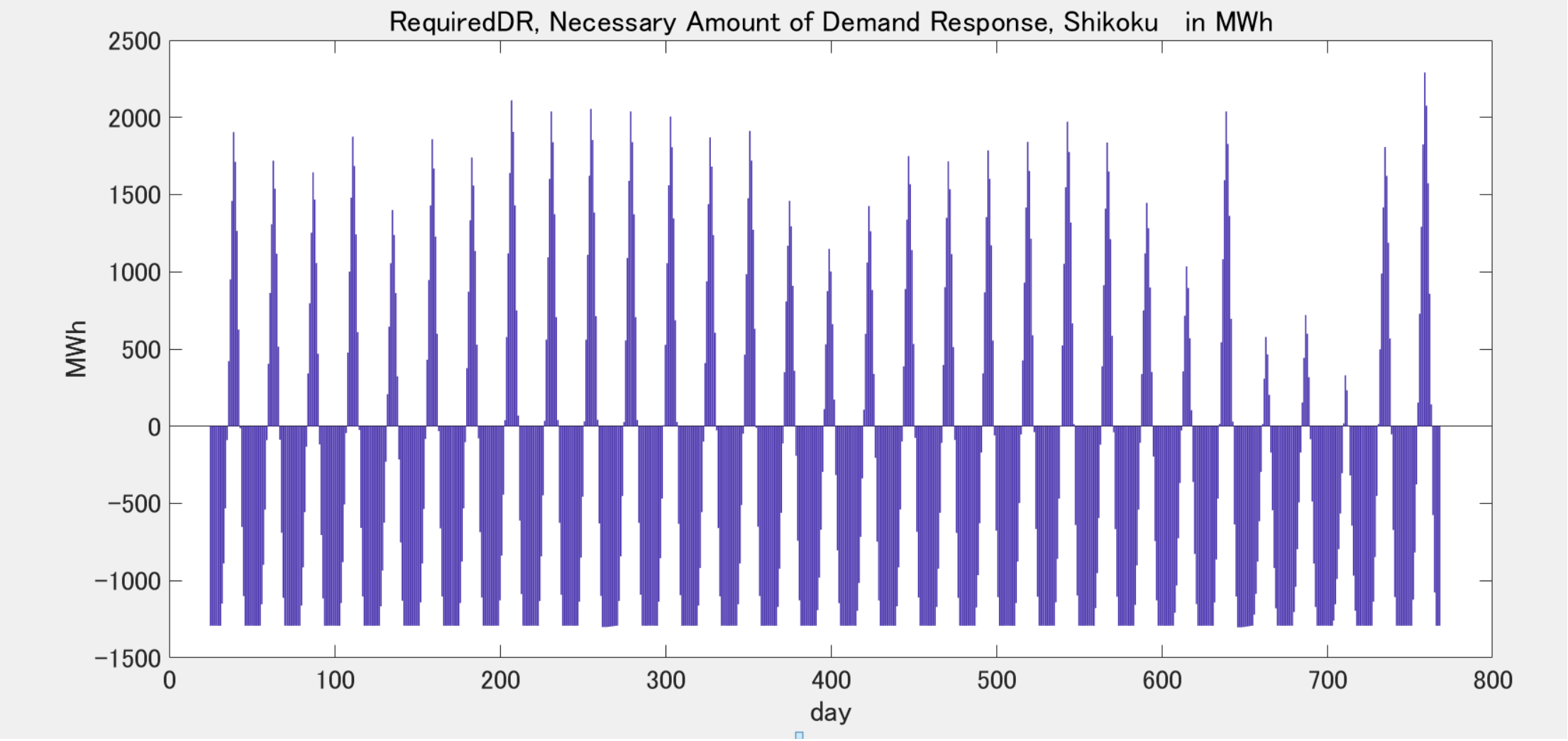


Coal plant operation ratio/ rated capacity

■ **High** Scenario in **Shikoku** zone

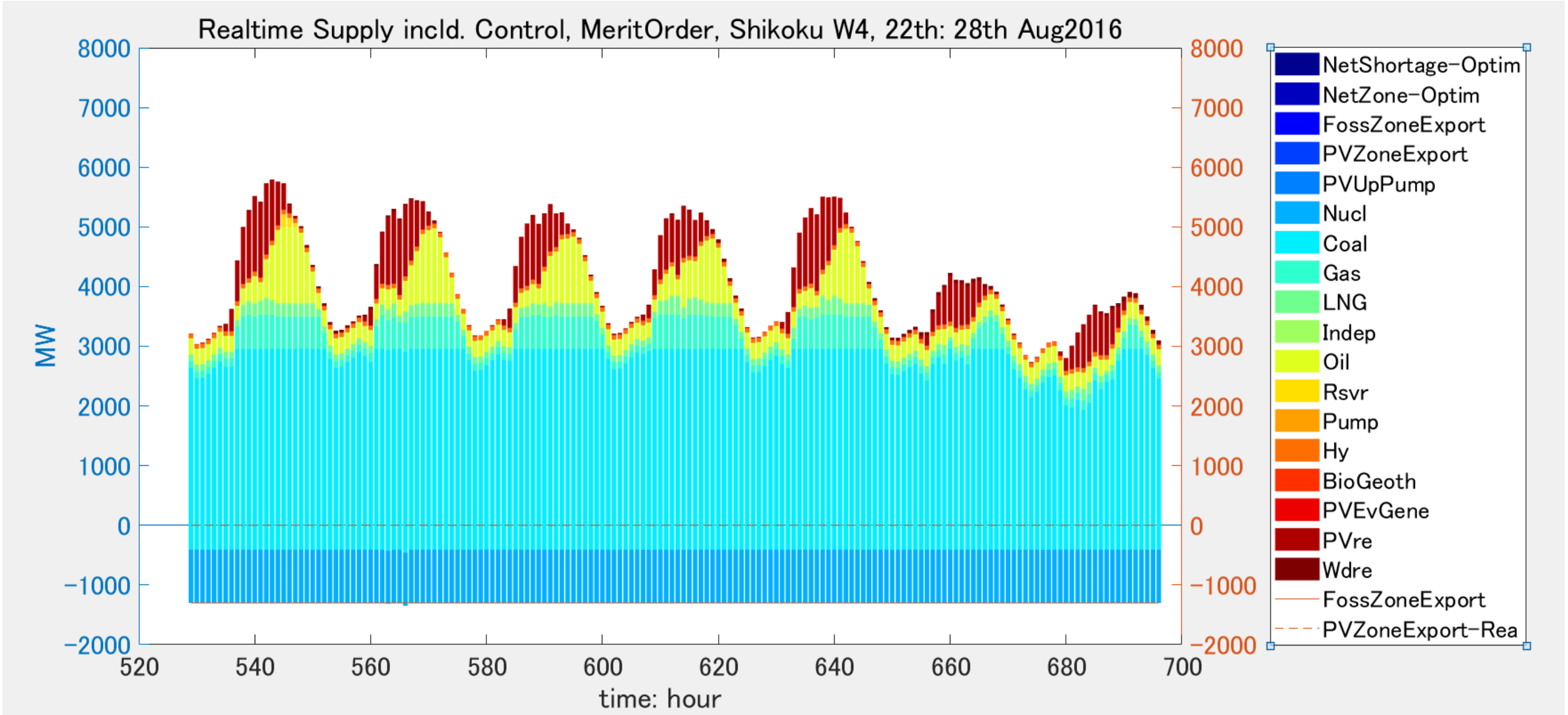
2500 MWh of DR (Demand Response) would be necessary.

Mainly Heap-Pump systems are needed to be used as DR.



■ Base 1 Scenario in **Shikoku** zone in 2016 Aug.

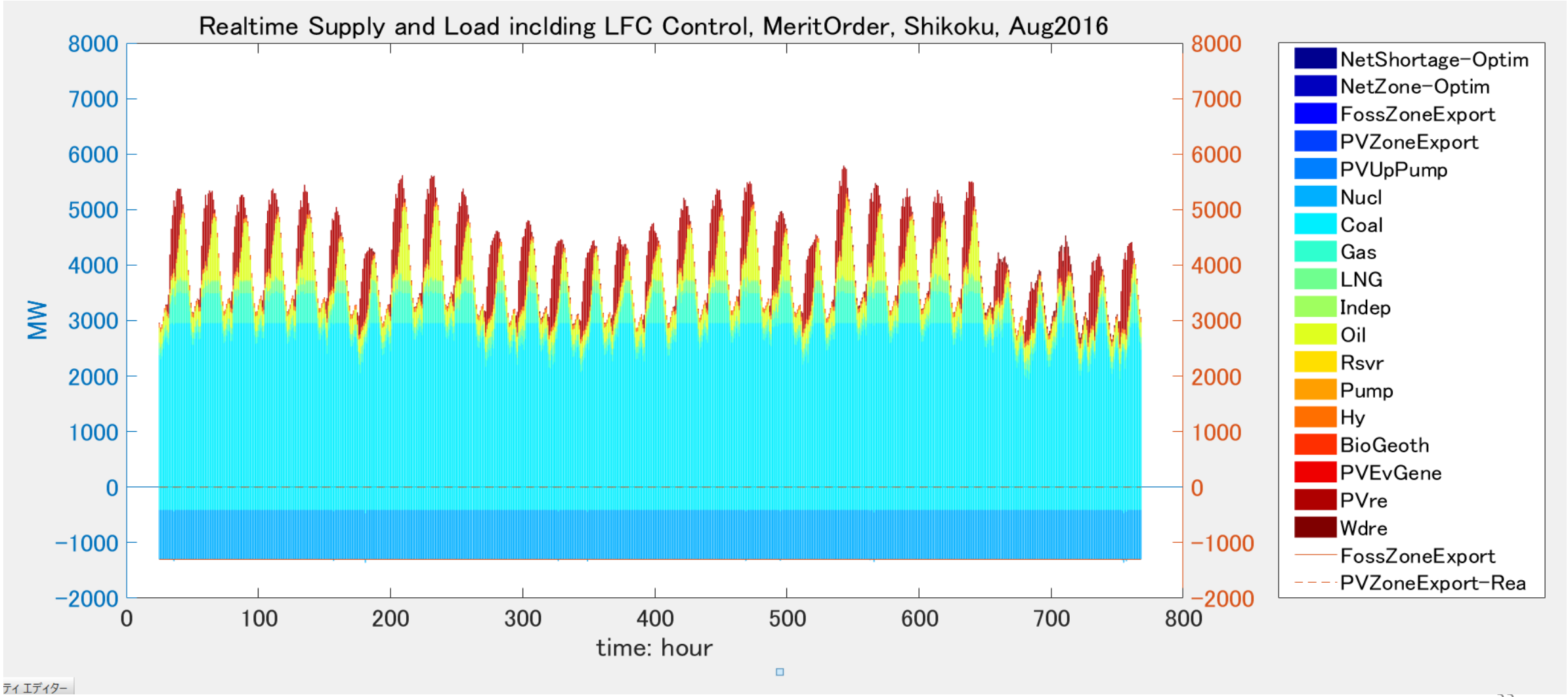
- 0.9GW Nuclear power is in operation,
- 1.3GW Coal power is transported to Interzone lines.



■Base 1 , **Shikoku** zone in 2016 Aug

0.9 GW Nuclear is in operation

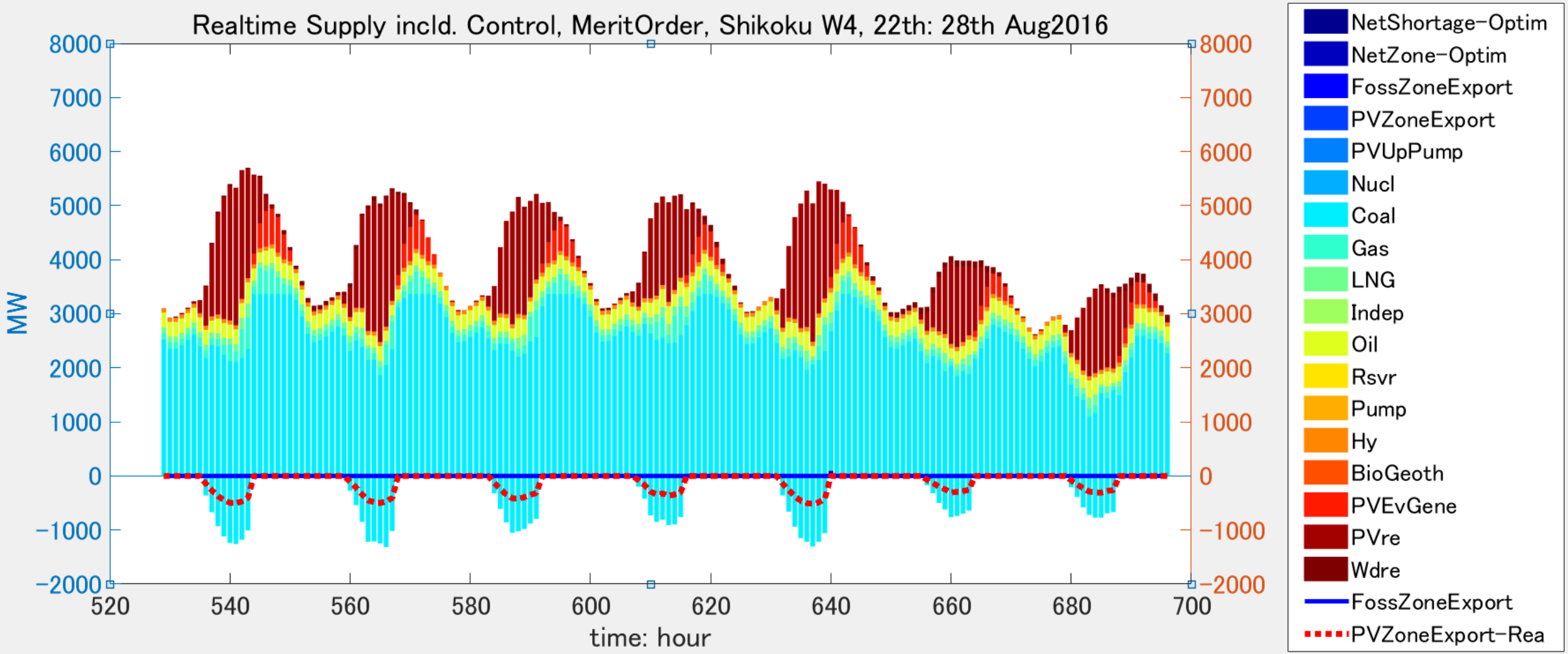
Coal power is transported to Interzone lines (Long-Term, Scheduled flow has a priority).



■ **High** Scenario, **Shikoku zone**

30% of PV Power is Pumped Up and evening Generation

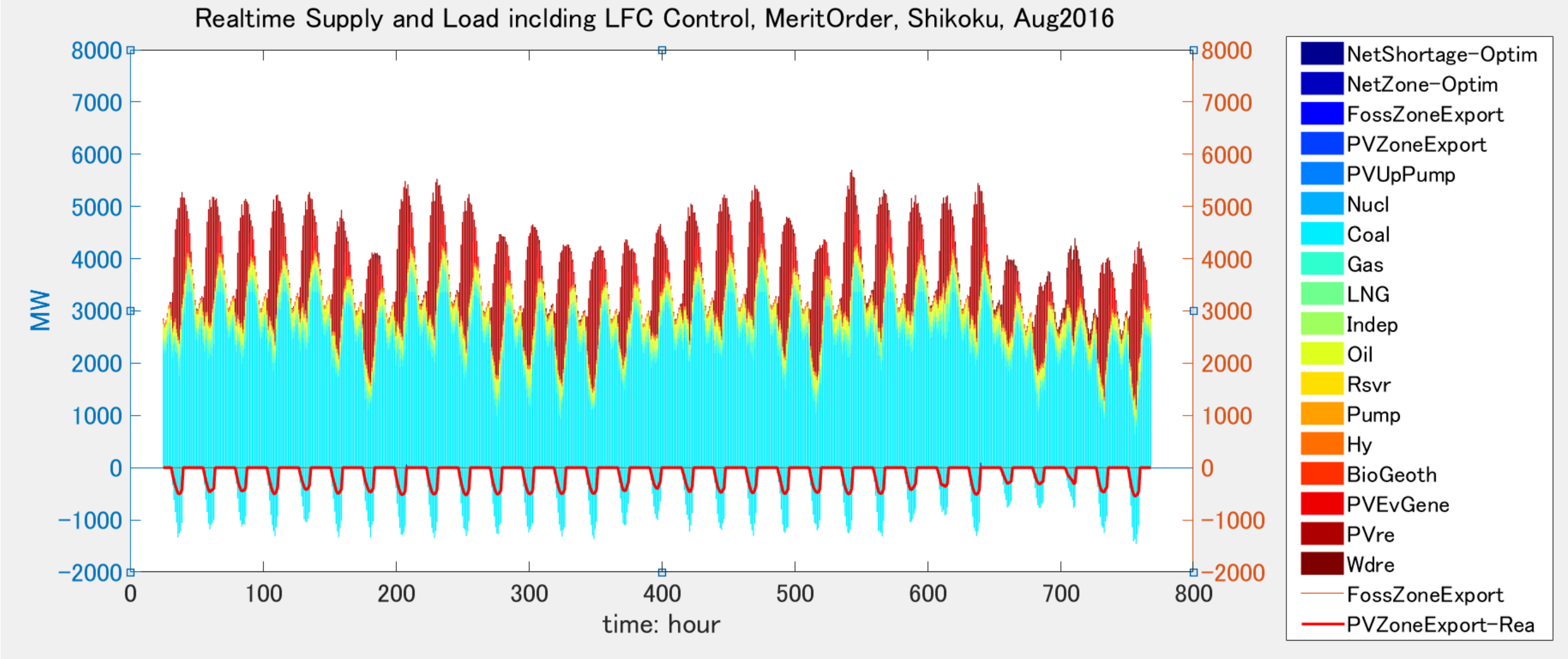
20% of PV Power is transported to Interzone time lines (priority)



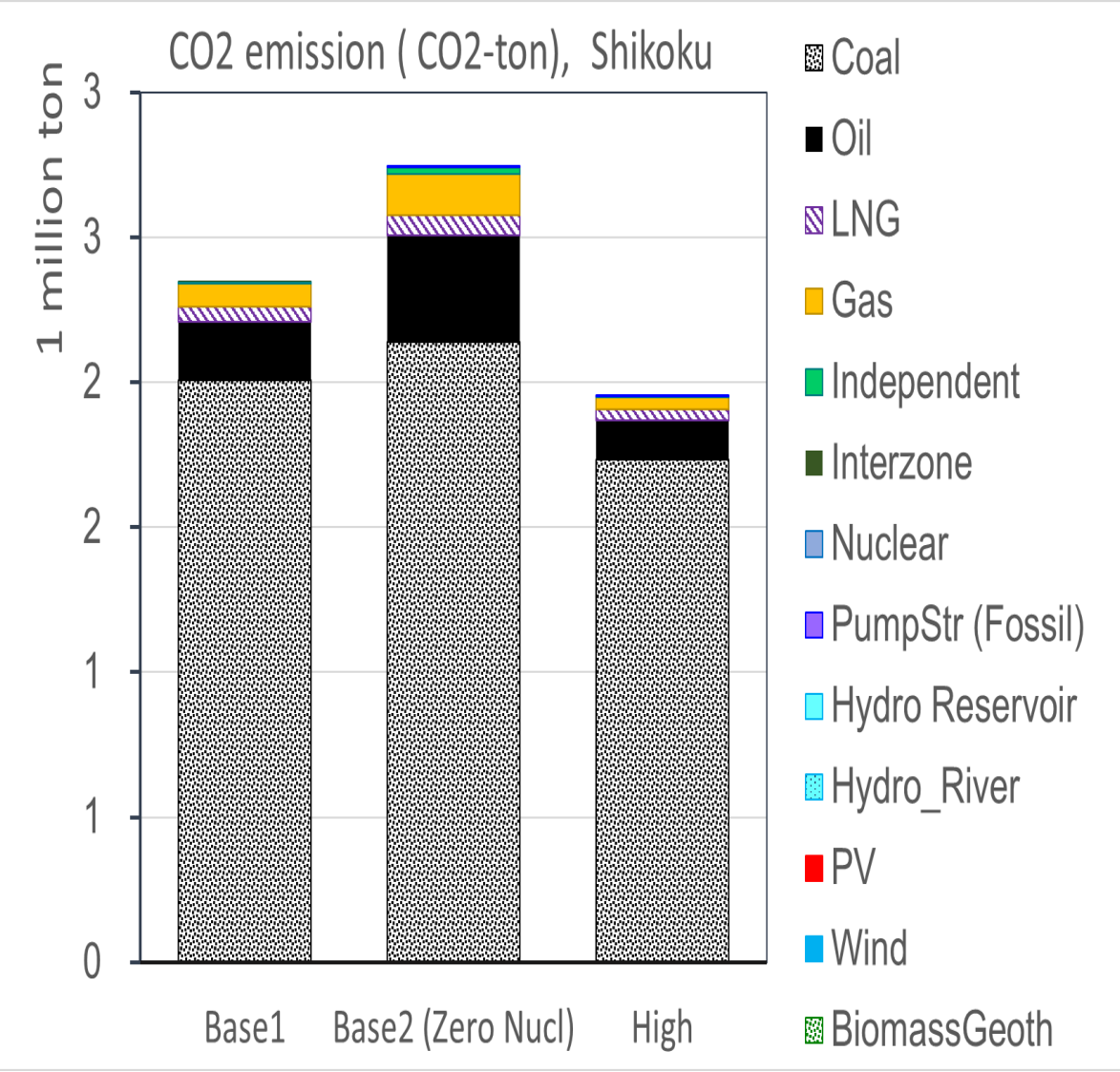
■High Scenario **Shikoku** zone in August

In All 31 days, PV power is Pumped-Up.

Risks of Supply Shortage would be small under high PV penetration conditions.



Results in **Shikoku** zone

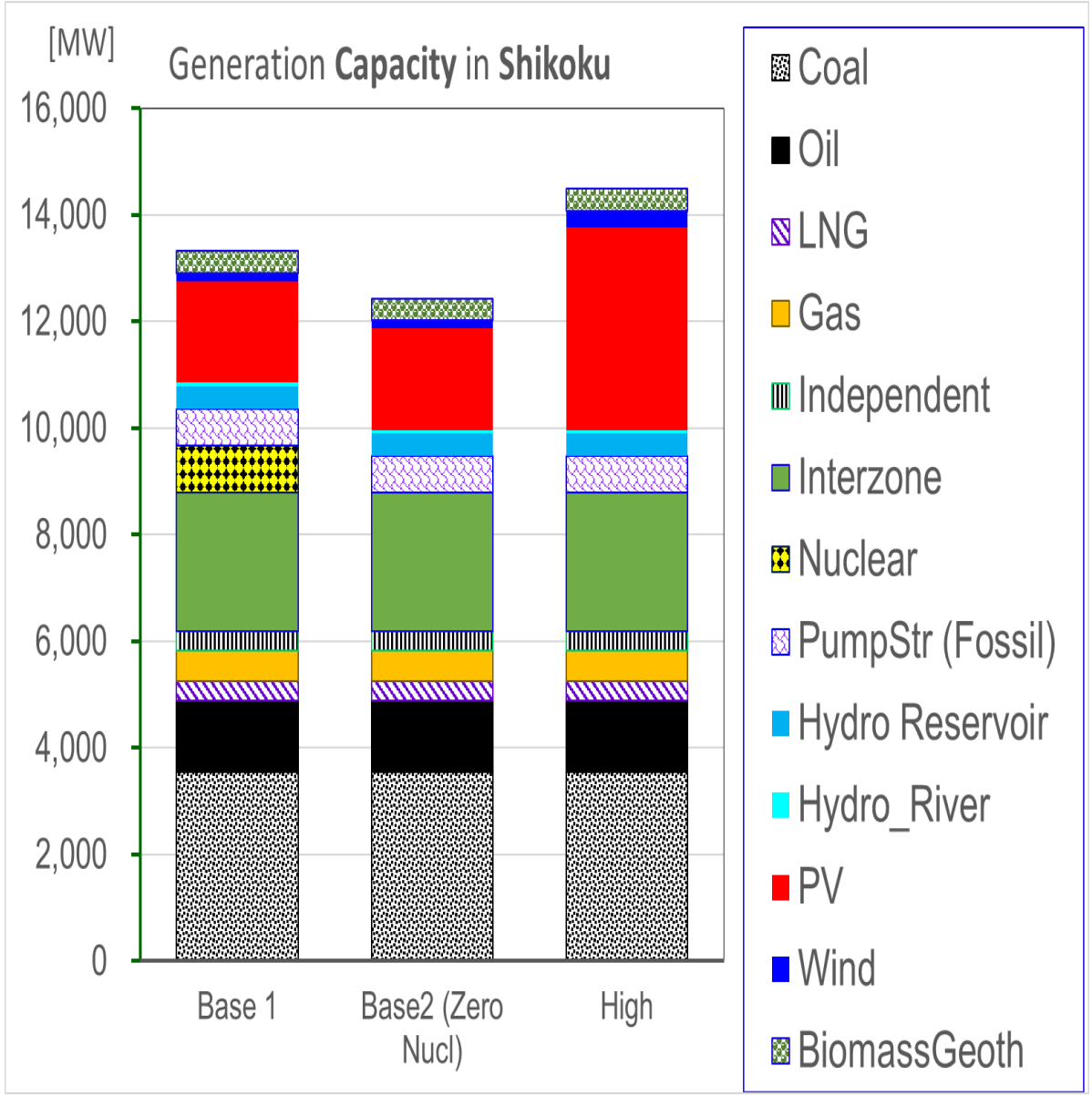


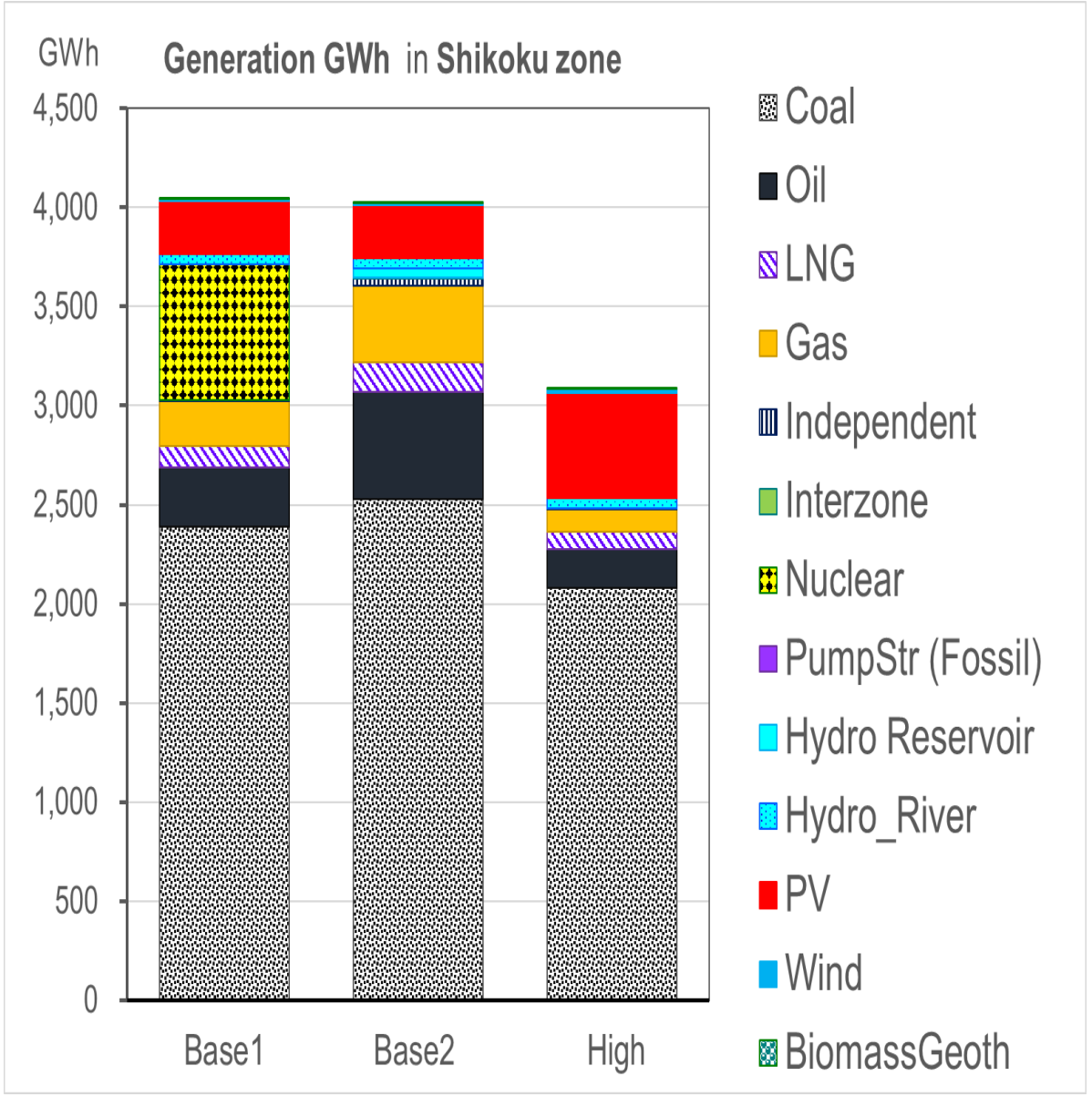
Renewable Share in Total Generation [% of MWh]		
Base1	Base2 (Zero Nucl)	**High**
8%	**9%**	**20%**

Average CO2 emission per kWh [CO2-kg/kWh]		
Base1	Base2 (Zero Nucl)	**High**
0.58	**0.68**	**0.63**

Average Fuel Cost [JPY/kWh]		
Base1	Base2 (Zero Nucl)	**High**
6.45	**8.49**	**6.11**

Results in **Shikoku** zone





■Conclusions in **Shikoku** Zone

- High Scenario shows all 31 days in August get PV Pump-Up mode, even rainy days.
- Even in peak demand period (Summer), a risk of supply shortage is small with zero nuclear operation.
- High Scenario shows as follows (**compared to Base 2, Zero Nuclear case**):
- **Renewable energy share** has increased from **9%** to **20%**
- **CO2 emission** has decreased from **0.68** to **0.63** [CO2kg/kWh]
- **Fuel cost** has decreased from **8.49** to **6.11** [JPY/kWh]
- DR (Demand Response) is required to balance large-scale oversupply from PV power.
- 2500 MWh of DR is required in summer.
- PV Pump-Up operation is recommended in summer peak demand period.
- Excess PV/ wind power must be transported to Interzone tie-lines as a priority. It is useful to reduce CO2 and fuel cost.

Thank you for attention

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